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-Technical Report-

Evaluation of Instrumentation for Measuring Undissolved Water in Aviation Turbine Fuels per ASTM D3240

Joel Schmitigal

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November 2015

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Introduction

Fuel quality assurance is accomplished by conducting periodic fuel sampling for the condition monitoring of aviation fuel by detecting, measuring, and reporting the levels of contaminants in the fuel. The currently accepted methods for measuring free water contamination of fuel supplies include:

- ASTM D3240 – Standard Test Method for Undissolved Water in Aviation Turbine Fuels
- ASTM D4176 – Standard Test Method for Free Water and Particulate Contamination in Distillate Fuels (Visual Inspection Procedures)

Excess free water in aviation fuel can diminish the lubricative properties of the fuel and lead to icing of fuel filters at low temperatures commonly found at high altitude and artic operations. The presence of free water in fuel storage systems can also lead to the growth of microorganisms at the interfacial layer of the fuel and water which can lead to fuel quality degradation, filter plugging, and fuel system corrosion. Free water contamination (droplets) may appear as fine droplets or slugs of water in the fuel systems and is controlled by the use of filter separators and coalescers in fueling handling equipment.

Current standards, such as MIL-STD-3004, Department of Defense Standard Practice for Quality Assurance/Surveillance for Fuels, Lubricants, and Related Products and Field Manual No. 10-67-2, Department of the Army Manual for Petroleum Laboratory Testing and Operations, specifies limits for free water and particulate matter in aviation fuels. Per Army requirements, at a minimum free water is checked daily and cannot exceed 10 parts per million (ppm) (1) (2).

In the early 1960's the US Navy developed the Aeronautical Engine Laboratory **(**AEL**)** free water detector and the associated methodology for detecting free water (3). Later in the decade Exxon refined this method to utilize a 25mm uranine dye treated pad, implemented the use of an iris diaphragm to vary the results, and the use of a single built in comparison standard. Gammon Technical products further refined the AquaGlo testing apparatus used in ASTM D3240, under license from Exxon, and has introduced several refinements over the years. The test works by passing a known volume (500 mL) of fuel through an uranine dye-treated filter pad. The free water in the fuel will react with the uranine dye in the filter pad. The pad is then subjected to an ultraviolet (UV) light source that causes the dye that has been in contact with the free water to fluoresce. The fluorescence of the test pad is compared to a known standard, and the free water in the fuel sample is provided in parts per million by volume. Water levels higher than 12 ppm can be calculated by reducing the sample size by a known amount.

Instrumentation that reads the filter pads include the Aqua-Glo Series V from Gammon Technical Products, the JF-WA1 from D-2 Incorporated, and the newly introduced Digital Aqua-Glo instrument from Gammon Technical Products, Figure 1.

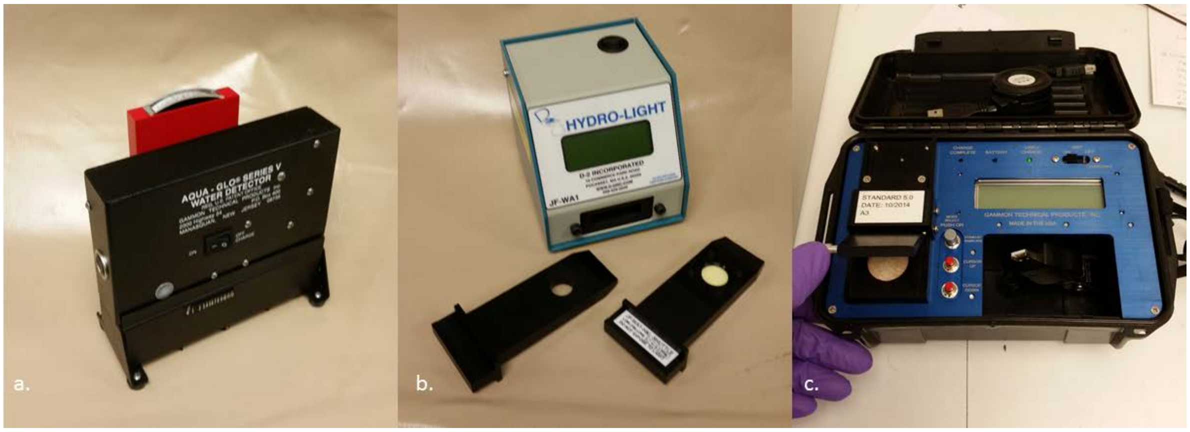

Figure 1. a. Aqua-Glo Series V from Gammon Technical Products; b. JF-WA1 from D-2 Incorporated and c. Digital Aqua-Glo instrument prototype from Gammon Technical Products.

1. Evaluation

The test plan for evaluating the Digital Aqua-Glo pad reader from Gammon Technical Products involved the production of contaminated fuels with varying levels of solid and free water contamination. As a basic evaluation, only one of each instrument was utilized. The AquaGlo V was an older unit and the Digital units were both new. The EI 1581 test facility at Southwest Research Institute was used to develop these fuel samples. Uranine dye-treated filter pads were prepared by passing 500mL of fuel through the filter pad as specified in ASTM D3240. When free water content was expected to be greater than 10 ppm the sample size was cut in half to 250mL and when water content was expected to be greater than 24ppm sample size was cut to 100mL. The filter pad was read on the Aqua-Glo Series V instrument from Gammon Technical Products, the JF-WA1 from D-2 Incorporated, and the Digital Aqua-Glo instrument and the appropriate conversion factors were then applied to instrument readings to provide ppm if applicable. A total of 70 samples were analyzed during the evaluation. The test matrix found in Table 1 provides the contaminate levels tested.

			Free water Concentration PPM					
			0	5	10	15	20	30
Test Dust Concentration (mg/L)	A3	2.5	x		x	x		x
		2	x		x	x		x
		1	x	x	x	x	x	
		0.5	x		x	x		x
		0.25	x		x	x		x
	A2	2.5	x		x	x		x
		2	x		x	x		x
		1	x		x	x		x
		0.5	x	x	x	x		
		0.25	x		x	x		x
	A1	2.5	x		x	x		x
		2	x		x	x		x
		1	x	x	x	x		
		0.5	x	x	x	x		
		0.25	x	x	x	x		

Table 1. Test Matrix

2. Analysis

The D-2 Incorporated JF-WA1 was used as a baseline measurement to compare the Gammon Technical Products Aqua-Glo Series V and Digital Aqua-Glo instruments. Samples that fell below 5.0 ppm on the JF-WA1 instrument were found to vary by an average of 2.7ppm when read on the Aqua-Glo Series V instrument, an average of difference of 131%. Samples that were measured to be greater than 5.0ppm on the JF-WA1 instrument varied by an average of 4.0ppm between when tested on the Aqua-Glo Series V instrument, for an average of 61.4% different. The measurement variation between the two instruments exceeded the established reproducibility of the Aqua-Glo instrument as established in ASTM D3240, Equation 1, in 60 of 70 samples tested. JF-WA1 instrument reproducibility is provided for reference in Equation 2. These are the results of this abbreviated test procedure, which is not as thorough as an ASTM 'Round Robin' test. The AquaGlo Series V results showed errors which were determined to be the result of a faulty instrument.

$$R = 0.54083x^{0.8058} \text{ ppm}$$

Equation 1. Aqua-Glo Reproducibility

$$R = 0.36913x^{0.4997} \text{ ppm}$$

Equation 2. JF-WA1: Reproducibility

Samples that fell below 5.0 ppm on the JF-WA1 instrument varied by an average of 0.4 ppm, an average of difference of 29.7% when measured on the Digital Aqua-Glo reader compared to the from the JF-WA1 results. Samples that were measured to be greater than 5.0 varied by an average of 0.6 ppm between the JF-WA1 instrument and the Digital Aqua-Glo, an average of difference of 8.44%. The measurement variation between the two instruments exceeded the established reproducibility, Equation 3, of the Digital Aqua-Glo reader in 7 out of 70 samples tested.

$$R = 0.40703x^{0.5771} \text{ ppm}$$

Equation 3. Digital Aqua-Glo Reproducibility

3. **Data**

A-3 Dust	0.25 mg/L			0.5 mg/L			1.0 mg/L			2.0 mg/L			2.5 mg/L			2.0 mg/L			2.5 mg/L		
Water	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**
ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
0	0.7	2	1.3	0.7	2	1.1	1.3	3.5	1.7	0.8	3	1.3	0.7	2	1.1	1.1	3	4.1	1.2	3	1.6
5	--	--	--	--	--	--	5.0	9	5.1	--	--	--	--	--	--	4.3	7.5	4.0	4.0	8	3.9
10	6.6	12	6.8	5.8	12	6.4	8.8	14	8.6	8.6	18	7.8	8.0	12	7.8	7.5	12	7.9	8.0	14	7.2
15	12.2	19	11.4	15.2	>24	14.8	10.0	16	9.2	16.0	>24	15.8	16.2	>24	16.6	14.4	22	13.8	18.8	>24	17.0
20	--	--	--	--	--	--	14.8	12	14.0	--	--	--	--	--	--	--	--	--	--	--	--
30	28.5	45	19.5	29.0	45	27.5	--	--	--	26.5	42.5	24.0	18.5	30	17.5	--	--	--	--	--	--

A-2 Dust	0.25 mg/L			0.5 mg/L			1.0 mg/L			2.0 mg/L			2.5 mg/L		
Water	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**
ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
0	1	2.4	1.5	1.2	3	1.7	1	3	1.2	1.6	4	2.0	1.5	4	1.8
5	--	--	--	5	9.5	5.0	--	--	--	--	--	--	--	--	--
10	9	14	8.0	8.8	16	8.0	10.4	18	9.8	9.8	18	9.8	10.2	18	9.6
15	17	>24	16.6	15.2	>24	14.0	14	20	13.2	14.4	>24	13.6	15.0	>24	14.6
20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	28	45	24.5	--	--	--	17	30	17.5	35.5	60	33.5	32.0	60	31.5

A-1 Dust	0.25 mg/L			0.5 mg/L			1.0 mg/L			2.0 mg/L			2.5 mg/L		
Water	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**	**D-2**	**Gammon V**	**Gammon D**
ppm	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**	**ppm**
0	1.7	4.5	1.9	1.3	4.5	1.6	1.5	3.5	1.7	1.5	4	1.9	1.2	3	1.6
5	5.2	10	5.4	5.5	10	3.8	4.5	9	4.8	--	--	--	--	--	--
10	11.2	18	10.4	10.8	18	9.2	9.2	17	8.4	11.0	18	10.6	10.2	16	9.8
15	15.2	>24	15.8	17.6	24	13.2	12.4	19	11.0	15.0	>24	14.2	12.6	21	11.6
20	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
30	--	--	--	--	--	--	--	--	--	29.5	55	21.0	32.5	55	29

Table 2. Free water measurements utilizing D-2 Incorporated JF-WA1, Gammon Technical Products Aqua-Glo Series V, and Digital Aqua-Glo instruments with varying levels of free water and particulate contamination.

4. **Conclusions**

Discussions with personnel from Gammon Technical Products indicate that the Aqua-Glo Series V instrument was malfunctioning during the evaluation. The instrument was calibrated every hour. There was no way for the user to determine if the instrument was operating correctly or not. The Aqua-Glo Series V, and similar previous instruments, have been used by the aviation industry for over 40 years, and is the referee method for ASTM D3240. For this reason it is acceptable to accept this conclusion from Gammon Technical Products upon their evaluation of the data presented in this report.

It should be noted that both the Digital Aqua-Glo and the JF-WA1 instrument have calibration checks to verify instrument operation. The Aqua-Glo Series V instrument requires frequent recalibration but does not have a separate verification method which can lead the operator to obtain incorrect readings due to an instrument malfunction as appears to have occurred during this evaluation. Gammon Technical products has stated that a verification check for the analog instrument will be introduced in the near future. The JF-WA1 instrument requires annual factory recalibration but the manufacture has stated that, “The annual calibration can be extended indefinitely as long as the provided verification shuttle meets 1/2 the tolerance shown for both values.” The Digital Aqua-Glo performs an internal recalibration before each test reading.

Both the JF-WA1 from D-2 Incorporated and Digital Aqua-Glo pad reader from Gammon Technical Products are easier to operate than the Aqua-Glo Series V instrument and provided results commensurate with the analog instrumentation and should be considered for field use for free water evaluation of jet fuel.

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List of Symbols, Abbreviations, and Acronyms

AEL	Aeronautical Engine Laboratory
ASTM	ASTM International
D-2	D-2 Incorporated
EI	Energy Institute
MIL	Military
mL	Milliliter
PPM	Parts Per Million
STD	Standard
UV	Ultraviolet
US	United States